Experiments on Vortex-Excited Oscillations of Axially-Varying Cylindrical Structures in Non-Uniform Approach Flow

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LONG-TERM GOALS

The long-term goals of this experimental investigation are to identify and understand the important fluid-structure interaction mechanisms that occur during vortex-excited vibrations of axially-varying cylindrical structures in non-uniform flow fields.

OBJECTIVES

- To study the aerodynamic response of vortex-excited pivoted and cantilevered axially-varying cylinders to uniform and linearly-varying shear flows.
- To investigate the effects of body geometry and approach flow non-uniformity on the wake parameters such as: vortex formation length, base pressure and Strouhal number.
- To investigate the near wake flow structure before, during and after lock-in.
- To investigate the observed hysteresis loops and phase jumps in the lock-in regime.
- To provide adequate data for van der Pol oscillator modeling of the vortex shedding process for self-excited cylindrical structures in non-uniform flow fields.

APPROACH

The experimental approach utilizes the low-turbulence, in-draft wind tunnel and the water tunnel at the Hessert Center for Aerospace Research at the University of Notre Dame. A curved screen is used to generate linear shear flows in the wind tunnel. A hot-wire rake capable of measuring sixteen signals simultaneously is employed for measurements of mean and fluctuating velocities. Power spectral densities and phase relationships are extracted from these signals to characterize the near-wake flow structure. Instantaneous displacement measurements of the cylinder amplitudes are made optically using a laser embedded in the model and a lateral effect detector. In addition, an accelerometer mounted on the model provides acceleration data. Flow visualization via smoke wire in the wind tunnel and lead precipitation in the water tunnel is integrated to reveal the three-dimensional character of the body and fluid oscillations in the near wake.

WORK COMPLETED

Computer-controlled wind tunnel investigations into nine different cases of freely oscillating, pivoted, cylindrical cylinders were tested. Straight and tapered cylinders were tested in uniform flow and shear flows that aided or opposed the taper. While past tests of these cases were conducted by manually controlling the tunnel velocity, the computer control in the new tests allowed a much greater number of

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velocity points to be considered. The greater number of points allowed a closer examination of any hysteresis effects that may be present when increasing or decreasing the velocity through the lock-in range. Each case consisted of a rigid cylinder pivoted at one end with a bearing and stiffened by two transverse springs at the other. The bearing and springs allowed for oscillatory movement only in the cross-flow direction. Displacement measurements were made for each case to identify critical flow regimes for subsequent wake velocity measurements. To these pivoted cylinder cases were added several lightweight, thin-walled, cantilevered cylinder cases in the same uniform and shear flows. One straight aluminum cylinder and one slightly tapered composite cylinder were tested.

Sixteen channels of hot-wire anemometers were built in-house to conduct cylinder wake surveys using hot wires at multiple points. Sixteen hot-wire probes distributed spanwise in the body's wake produced time series data for the wake simultaneous to the cylinder displacement. Figure 1 shows the rake fixed behind a tapered cylinder. Thus far, wake profiles have been measured for the cantilevered cylinder cases.

Flow visualization work was conducted on a sinuous model in a water tunnel to simulate a wavy, fixed cable. Two models of circular cross section – with shapes of different wavelength and amplitude – were constructed for use with the lead precipitation technique. Both spanwise and streamwise cross sections of the wake were observed.

RESULTS

The non-uniformities considered in this work – linearly-varying velocity and/or linearly-varying cylinder diameter – significantly increased the reduced velocity range for which lock-in was observed. Some cases had lock-in ranges nearly triple that of the uniform cylinder in uniform flow case. The reduced velocity at which the displacements reached a maximum and the magnitude of that maximum varied with the direction of both the taper and the shear with respect to the pivot location. Investigation of the trends of these parameters is still in progress.

Curves of tip displacement versus reduced velocity for the pivoted cylinder cases involving non-uniformities showed a trend of having a more gradual slope on one side of the maximum than that of the other as illustrated in Figure 2. This is related to the location of the locked-in portion of the wake relative to the pivot. As the velocity is increased to traverse the lock-in range the amplitude reaches a maximum quickly when the portion of the wake furthest from the pivot locks in first. When the first part of the wake to lock in is near the pivot, the amplitude approaches the maximum more gradually as the rest of the wake begins to lock onto the body's frequency. This is true conversely for the portions of the wake that are last to be locked in. These observations are somewhat intuitive considering that the body's amplitude decreases to zero as the pivot is approached precluding lock-in in that region. This steep and gradual slope behavior of the slope appears to be unique to this pivoted-type of setup. It has not been reported for all vortex-induced vibration scenarios.

The cantilevered cylinder cases show amplitudes approximately an order of magnitude smaller than their pivoted counterparts. This is reasonable given the greater values of the mass-damping parameters for the cantilevered cylinders. Multiple maxima in the displacement amplitude versus reduced velocity curves occurred in some, but not all cases. The maximum amplitude for those cases with a single peak was much higher than those of the multi-peak cases. Further work must be done to determine the cause of these two types of responses. Shear flow with its maximum velocity far from the fixed end shifted the lock-in range to a larger reduced velocity and narrowed the lock-in region. This narrowing

is the opposite of the effect of shear in the pivoted cases. When the maximum velocity was near the fixed end, amplitudes were much smaller without the narrowing seen in the previous case.

Hot-wire measurements with the sixteen sensor rake in the wake of a cantilevered cylinder in shear flow showed strong spanwise correlations within cells with a dramatic drop across cell boundaries. Further work into the time-domain behavior of the wake is forthcoming.

Flow visualization studies on models of cylindrical cross section with sinusoidal amplitude perturbations in the streamwise direction revealed significant changes in the wake structure compared to that of a uniform cylinder. The wake width varied in the spanwise direction being much wider downstream of “troughs” in the cylinder shape. Visualizing planes parallel to both the velocity and the cylinder axis showed that wake flow converges toward the regions downstream of the “peaks” in the cylinder shape.

IMPACT/APPLICATIONS

The experimental results of the configurations tested are of a general nature and can be used to improve physical models to predict unsteady lift and lock-in phenomena in many offshore systems.

TRANSITIONS

We expect the results obtained from the present experiments to provide the necessary data for modelers to formulate more sophisticated wake-oscillator models.

RELATED PROJECTS

We are in close collaboration with the Division of Applied Marine Physics, University of Miami on their project “Modeling vortex-excited vibrations of axially-varying cylindrical structures in non-uniform flow fields”; Principle Investigator: Richard A. Skop. Also, in cooperation with Prof. Pratap Vanka of the University of Illinois, our water tunnel studies complement their recently completed direct numerical simulation of vortex shedding from a circular cylinder in a linear shear flow.

PUBLICATIONS

Balasubramanian, S., Haan, Jr., F.L., Szewczyk, A.A., and Skop, R.A., 1998: “On the existence of a critical shear parameter for cellular vortex shedding from cylinders in non-uniform flow,” *Journal of Fluids and Structures*, 12, 3-15.

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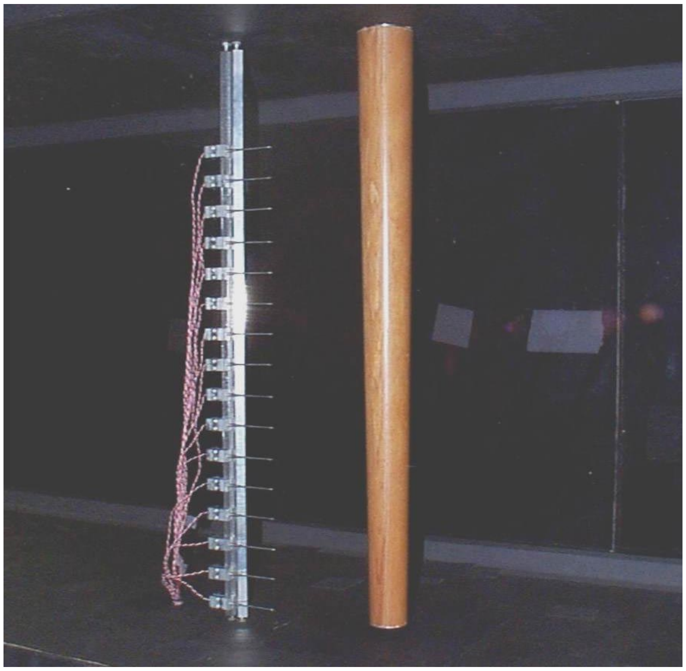

Figure 1. Picture from inside a wind tunnel test section showing the rake of sixteen hot-wire sensors in the wake of a tapered, circular cylinder.

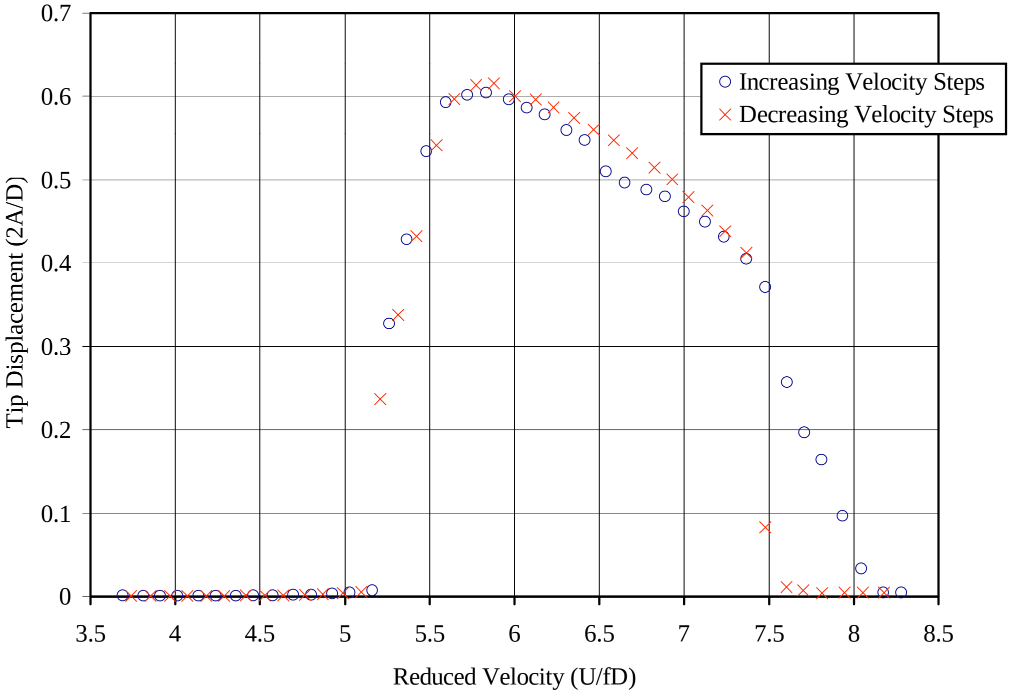

Figure 2. Plot of tip displacement amplitude versus reduced velocity for a uniform cylinder in a linear shear flow with maximum velocity away from the pivot point.